Strength and Shrinkage Cracking of Portland Cement Mortar Containing Different Superplasticizers

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Abstract

The effect of polycarboxylate (PC), polynaphthalene sulphonate (PNS) superplasticizers and calcium lignosulphonate (CLS) on strength, shrinkage and cracking of cement mortars was investigated by means of multi-channel ellipse ring shrinkage cracking test, free shrinkage and strength test under drying conditions. In general, PC, PNS and CLS increased initial cracking time and decreased cracking sensitivity of mortars. As for the effect of decreasing cracking sensitivity, the follow order was found: PC PNS CLS. At fixed W/B ratio and cement content, superplasticizers increased free shrinkage, but CLS slightly decreased free shrinkage of mortars. As for the effect of controlling volume stability of mortars, the order was found: CLS PC PNS. In comparison with controls, the maximum crack width with PC and CLS addition was less while the rate of cracking formation with PNS was greater. Using superplasticizers increased flexural and compressive strength of mortars at 28 days under drying conditions. In the aspect of increasing strength, superplasticizers were more effective than CLS, and PC was superior to PNS.

Keywords: Superplasticizers, Shrinkage cracking, Initial cracking time, Strength

1. Introduction

Early-age cracking due to shrinkage accelerates the deterioration of high performance concrete. Cracking is a main source of premature deterioration of the structure of concrete, which shortens the service life of the structure[1]. Water-reducing agent is an indispensable ingredient in high performance concrete. Water-reducing agents include superplasticizers and ordinary water-reducing agents. According to chief constituents, superplasticizers can be divided into four types: polynaphthalene series, melamine series, sulfamic acid series and polycarboxylate type. Polynaphthalene series superplasticizer (PNS) is a representative of the second-generation superplasticizers. Polycarboxylate-type superplasticizer (PC) is the third-generation high performance water-reducing agent, and its molecular structure exhibits comb-shape. PC can prevent slump loss of concrete, which has hardly any slump loss within 90 minutes, and don't obviously brings retarding effect. Thus, PC is one of the research and development focuses in chemical admixtures both in China and abroad[2,3]. Calcium

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lignosulfonate (CLS) is firstly and widely used in lignosulfonate water-reducing agents.

Previous studies on water-reducing agents tended to improve rheological properties and mechanical properties of cement-based materials[4-6].To the knowledge of the authors, there was lack of studies on the effect of water-reducing agents on early-age cracking and volume stability of cement mortars. The objective of the present investigation was determine the effect of water-reducing agents, namely, PC, PNS and CLS, on early-age shrinkage cracking and volume stability of cement mortars cured under drying conditions.

2. Experimental

2.1 Materials, mix proportions and specimen preparation

All mixtures were made with the same Portland cement(Lafarge). The cement has a Blaine fineness of 351m^2/kg and a Bogue calculated phase composition of 62.1% C_3S, 10.9% C_2S, 8.8% C_3A, and 10.9% C_4AF. Fly ash has a specific surface of 350 m^2/kg. Silica fume has a specific surface of 2.0×10^4 m^2/kg and density of 2.2 g/cm^3. The chemical compositions of these three materials are presented in Table 1. The fine aggregate was natural river sand with fineness modulus of 2.5.

Water-reducing agents used in this study include superplasticizers and CLS. Superplasticizers have PC and PNS. PC called GLENIUM SP-8N was a liquid product with a solid content of 18%, which had water-reducing ratio of over 30%. PNS called high-thickness-type UNF(H-UNF) was a powder product contained 0.5% sodium sulfate, which had water-reducing ratio of 15~25%. CLS was also a powder product, and its water-reducing ratio was only 10%.

Table 1
Chemical composition of cementitious materials

Components	Cementitious materials (%)		
	Cement	Fly ash	Silica fume
SiO_2	20.1	50.11	91.63
Al_2O_3	5.60	29.58	0.90
Fe_2O_3	3.58	6.20	0.93
CaO	63.43	3.92	0.13
MgO	1.06	1.79	1.78
SO_3	2.05	2.70	
free-CaO	0.46		
LOI	2.74	6.30	2.93

In terms of previous study on the optimized compositions of cementitious materials[7], the binder contained cement, fly ash and silica fume, which is in proportion to 55, 40 and 5 percent by mass. All mortars were designed at a fixed water-to-binder (W/B) ratio of by weight of 0.35 and binder-to-sand ratio by weight of 1:2. The type and dosage of Water-reducing agents in mortars are given in Table 2. For each mortar mixture, its fluidity was not less than 120mm.

Table 2
Type and dosage of mortars with water-reducing agents

Mix No.	1	2	3	4
Type of water-reducing agents		GLENIUM SP-8N	H-UNF	CLS
Dosage of water-reducing agents (%)		1.0	1.0	0.20

Note: The dosages of Water-reducing agents in mortars are the percent of binders by mass which contain cement, fly ash and silica fume.

2.2 Methods

Initial cracking time of cement-based materials directly reflects the ability to resist early-age shrinkage cracking. Multi-channel ellipse ring shrinkage cracking test was used to measure initial cracking time of mortar, which is schematically shown in Figure 1. Theoretical and modeling aspects of this ellipse ring-type specimen can be found elsewhere in the literature[8,9]. The dimensions of the steel ellipse ring are shown in Figure 2.

For the present study, the ellipse ring specimens were cast with mortars in the laboratory at 20±2 and over 50% relative humidity (RH), and vibrated for 30 seconds and then moist-cured at 20±1 and over 90% RH. After 18 hours, the outer molds of ring specimens were stripped off, and the top surface of the ring specimens was sealed with polyurethane so that drying would be only allowed from the lateral face. Then the specimens were placed in the drying chamber at 20±3 and 50±4% RH. Along the circumferential surface of the ellipse ring specimen, a strip of conducting layer was coated to connect the circuit that monitored initial cracking time. A curing period of 18 hours was selected to simulate minimal field-curing conditions, and also to accelerate the onset of cracking.

The multi-channel ellipse ring shrinkage cracking test can simultaneously monitor five specimens and precisely record initial cracking time. This setting greatly improves the accuracy and efficiency of measuring cracking sensitivity of cement-based materials.

Crack width of the mortar-ellipse-ring specimen was observed through the use of a magnifying microscope. Maximum crack width was determined once per week.

Mortar prisms (40mm×40mm×160mm) were cast to measure flexural and compressive strength. The specimens were molded at 20±2 and over 50% RH, and then moist-cured at 20±1 and over 90% RH. After 18 hours, the prism was demolded and then placed in the drying chamber at 20±3 and 50±4% RH. That is, the specimens for measuring both strength and initial cracking time were demolded at the same time, and cured under the same conditions.

Mortar prisms (25mm×25mm×280mm) were cast to measure free shrinkage. The specimens were molded at 20±2 and over 50% RH, and then moist-cured at 20±1 and over 90% RH. After 24 hours, the prism was demolded and its length was measured for the datum length. And then stored in the drying chamber at 20±3 and 50±4% RH. Length change measurements were made at 1day, 2days, 3days, 7days, 14days, 21days and 28days.

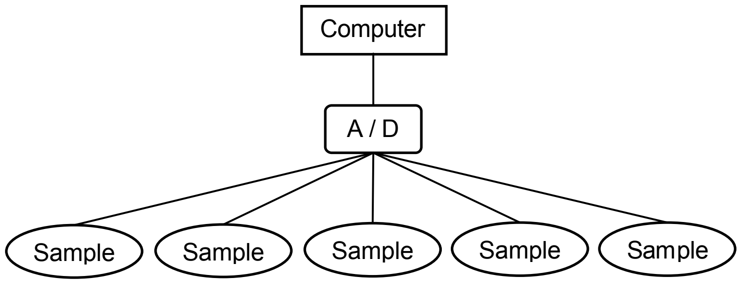

Fig. 1. Schematic diagram of multi-channel ellipse ring shrinkage cracking test

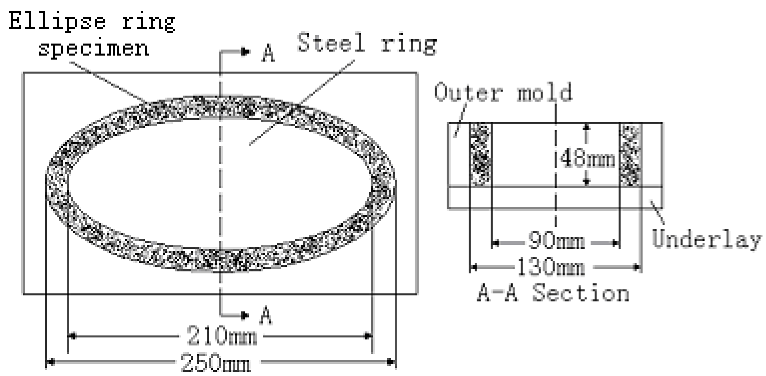

Fig. 2. Dimensions of the steel ellipse ring

3. Results and discussion

3.1 Initial cracking time

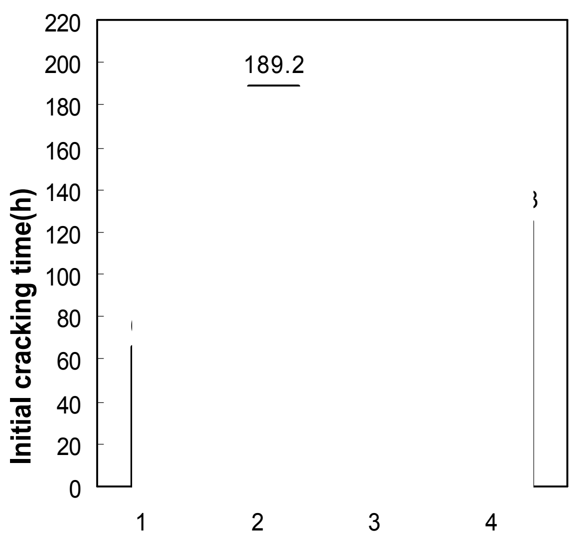

Fig.3. Effect of different kind of water-reducing agents on initial cracking time of mortars

The effect of different kind of water-reducing agents on initial cracking time of mortars is shown in Fig. 3. When the dosages of superplasticizers and CLS were 1.0% and 0.20% respectively, the order of initial cracking time of mortars was 2 >3 >4 >1 . Furthermore, 2 >>4 and 3 >>4 . It is obvious that the general effect of water-reducing agents is to increase initial cracking time of mortars. Consequently, water- reducing agents decrease cracking sensitivity of mortars. That is, when the dosages of water- reducing agents are appropriate, it can decrease cracking sensitivity of mortars. As for decreasing cracking sensitivity of mortars, the order is PC PNS CLS. From the viewpoint of crack resistance, PC should be considered as the best water-reducing agent.

3.2 Free shrinkage

It must be mentioned that the measure of free shrinkage can be commonly divided into two methods: one is to measure autogenous shrinkage under sealed conditions; the other is to measure drying shrinkage or total shrinkage under drying conditions. The latter was used in this study.

The effect of different kind of water-reducing agents on free shrinkage of mortars is shown in Figs. 4. The rate of free shrinkage of mortars incorporated 1.0% superplasticizers was increased at early age, and free shrinkage was apparently higher than that of control mortar. Moreover, free shrinkage of mortars with PC was lower than that of PNS at 28 days. However, free shrinkage of mortars with CLS was higher at early age and was slightly lower after 14 days in comparison with that of control mortar. It is clear that superplasticizers can increase free shrinkage of mortars, and PNS is more than PC in the aspect of increasing free shrinkage, but CLS can slightly decrease free shrinkage of mortars. As for the effect of controlling volume stability of mortars, the order is CLS PC PNS.

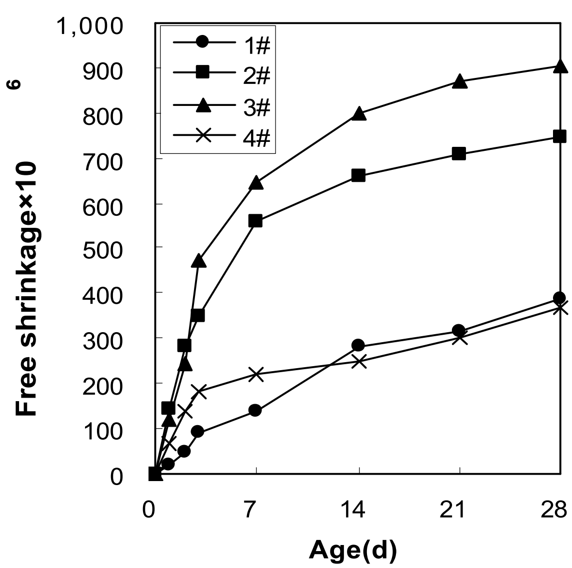

Fig.4. Effect of different kind of water-reducing agents on free shrinkage of mortars

This seems to be in agreement with precious findings of other investigators. Y.B. Yang and Z.Y Wen[10] reported that the use of different superplasticizers increases free shrinkage of mortars, especially at early age. This phenomenon was attributed capillary pore refinement. That is, pore volume of pore diameter from 3.2nm to 25nm was obviously increased in mortars with the superplasticizers.

3.3 Maximum crack width

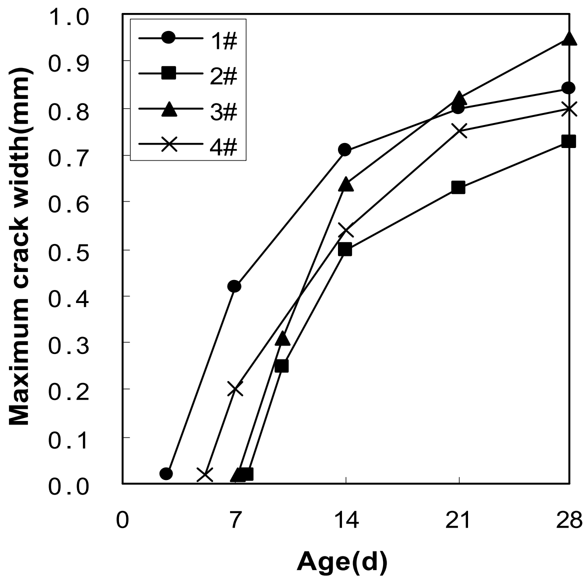

Fig.5. Effect of different kind of water-reducing agents on maximum crack width of mortars

The effect of different kind of water-reducing agents on maximum crack width of mortars is shown in Fig. 5. Maximum crack width of mortars with 1.0% PC or 0.2% CLS was decreased compared to that of control mortars. Especially, maximum crack width of mortars with 1.0% PC was the lowest. The development rate of maximum crack width of mortars with 1.0% H-UNF was faster in comparison with that of control mortars, and maximum crack width was higher than that of control mortars at 28 days. Thus, when volume stability and early-age cracking of cement-based materials are studied, not only initial cracking time and shrinkage are important, but also the development tendency of crack is rather significant. If so, the problem of volume stability of cement-based materials can be solved more effectively and faster, and the problem of durability due to crack is further resolved.

3.4 Strength

Flexural and compressive strength of mortars with water-reducing agents is shown in Table 3. Flexural strength of mortars with 1.0% PC and 1.0% H-UNF at the age of initial-cracking-time was increased by 48% and 28% as compared to the control, respectively. However, Flexural strength of mortars with 0.20% CLS at the age of initial-cracking-time was decreased by 10%. Using superplasticizers increased flexural and compressive strength of mortars at 28 days under drying conditions. Of course, flexural strength of mortars at the age of initial- cracking -time was connected with initial cracking time. To consider strength of mortars in Table 3 and initial cracking time of mortars in Fig. 3 together, it can be drawn that superplasticizers were more effective than CLS, and PC was superior to PNS in the aspect of increasing strength.

Table 3
Flexural and compressive strength of mortars with water-reducing agents

Mix No.	Flexural strength / MPa		Compressive strength / MPa	
	f_{ICT}	f_{28d}	R_{ICT}	R_{28d}
1#	2.9	4.8	20.5	29.1
2#	4.3	7.5	27.7	41.3
3#	3.7	6.7	24.1	34.4
4#	2.6	6.0	18.9	26.7

Note: f_{ICT} and f_{28d} are flexural strength of mortars at the age of initial-cracking-time and 28days, respectively;
R_{ICT} and R_{28d} are compressive strength of mortars at the age of initial-cracking-time and 28days, respectively;
The value of initial-cracking-time is shown in Fig. 3.

4. Conclusions

The following conclusions can be drawn from the present experiments:

1. The general effect of polycarboxylate-type superplasticizer (PC), polynaphthalene sulphonate superplasticizer (PNS) and calcium lignosulphonate (CLS) is to increase initial cracking time of mortars, and decrease cracking sensitivity of mortars. As for decreasing cracking sensitivity of mortars, the order is PC PNS CLS.
2. When keeping the constant W/B ratio and the content of cement pastes, superplasticizers can increase free shrinkage of mortars, and PNS is more than PC in the aspect of increasing free shrinkage, but CLS can slightly decrease free shrinkage of mortars. As for the effect of controlling volume stability of mortars, the order is CLS PC PNS.
3. Maximum crack width of mortars with PC and CLS was decreased compared to that of control mortars. But the development rate of maximum crack width of mortars with PNS was faster, and maximum crack width of mortars was higher at 28 days in comparison with that of control mortars.
4. Using superplasticizers increased flexural and compressive strength of mortars at 28 days under drying conditions. Superplasticizers were more effective than CLS, and PC was superior to PNS in the aspect of increasing strength.

Acknowledgments

This project was financially supported by the National Basic Research Program of China (973 Program) No. 2001CB610704-3 and the Hi-tech Research and Development Program of China (863 Program) No. 2005AA332010. The provision of materials by Beijing Lafarge cement is gratefully acknowledged.

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